ABOUT SOLAR ENERGY SIMULATION IN THE URBAN FRAMEWORK: THE MODEL OF COMPIEGNE

Benoit Beckers, Diana Rodríguez, Eduard Antaluca & Jean-Louis Batoz

Avenues – Urban Systems Engineering Department- Compiègne University of Technology

1. Introduction

In order to realize simulations of physical phenomena at the urban scale, such as solar potential, a detailed 3D geometrical model of Compiègne city centre is elaborated. Generally, the numerical simulation of physical phenomena at the urban scale is complex and computationally demanding. As the radiative exchanges are very sensitive to the geometry [1] it is necessary to take the real geometry into account. However, to reproduce the complete geometry with precise details leads to models computationally too expensive, so a drastic simplification of the geometry is necessary in order to preserve a good compromise between accuracy and computing time. This paper contains a description of the model of Compiègne, some results of the sensitivity analysis, the presentation of the roofs typology of Picardy France region for the evaluation of the local solar potential and the conclusions.

2. Description of the urban scale model of Compiègne

This model, based on a “manual” approach, has been tested with the software Heliodon 2. This software is a tool dedicated to control energetic and visual aspects of natural lighting in urban and architectural projects. [2] The model is composed of 21,735 triangles in STL format, separated in three layers: facade 3,759; window 7,402 and roof 10,574. The facades and roofs are composed by relevant surfaces, properly oriented and without solution of continuity. The roofs are modelled with dormers. The decorative elements have been neglected, as the fireplaces, the wall thickness and the ground. The windows are flat surfaces located at one centimetre out of the wall (Fig. 1 and 2).

Fig.1 Satellite image of the modelled zone.
Area: 61,900 m^2, perimeter: 1,190 m.

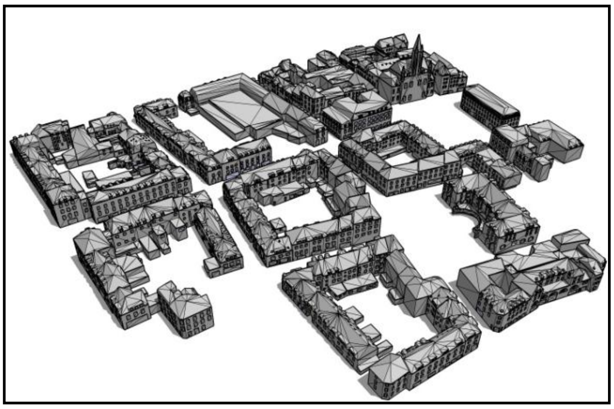

Fig 2 Aerial view of the model.

3. Impact of the urban context

To achieve the energy balance of a building, the current French thermal regulation (RT2005) requires quantification of solar gain. Because this quantification is currently performed without taking into account the effect of masks produced by the urban framework, the results are not accurate. The purpose of this section is to quantify in a realistic example the error resulting from the limitations of the calculations and to measure the influence of the external built environment.

For this purpose, we select a building and we perform two simulations of direct solar irradiance (blue sky conditions), the first one with the separate building and the second one with the urban environment. The differences between the energy values depend on the season, on the element that receives the energy and on the orientation and height of the surrounding buildings. We can see in the dashed frames that the north façade and the roof are relatively not affected by the environment. On the other hand, the windows and the facades are the most sensitive to the masking effect, because the surrounding buildings have a similar height compared to the building under study (Fig.3).

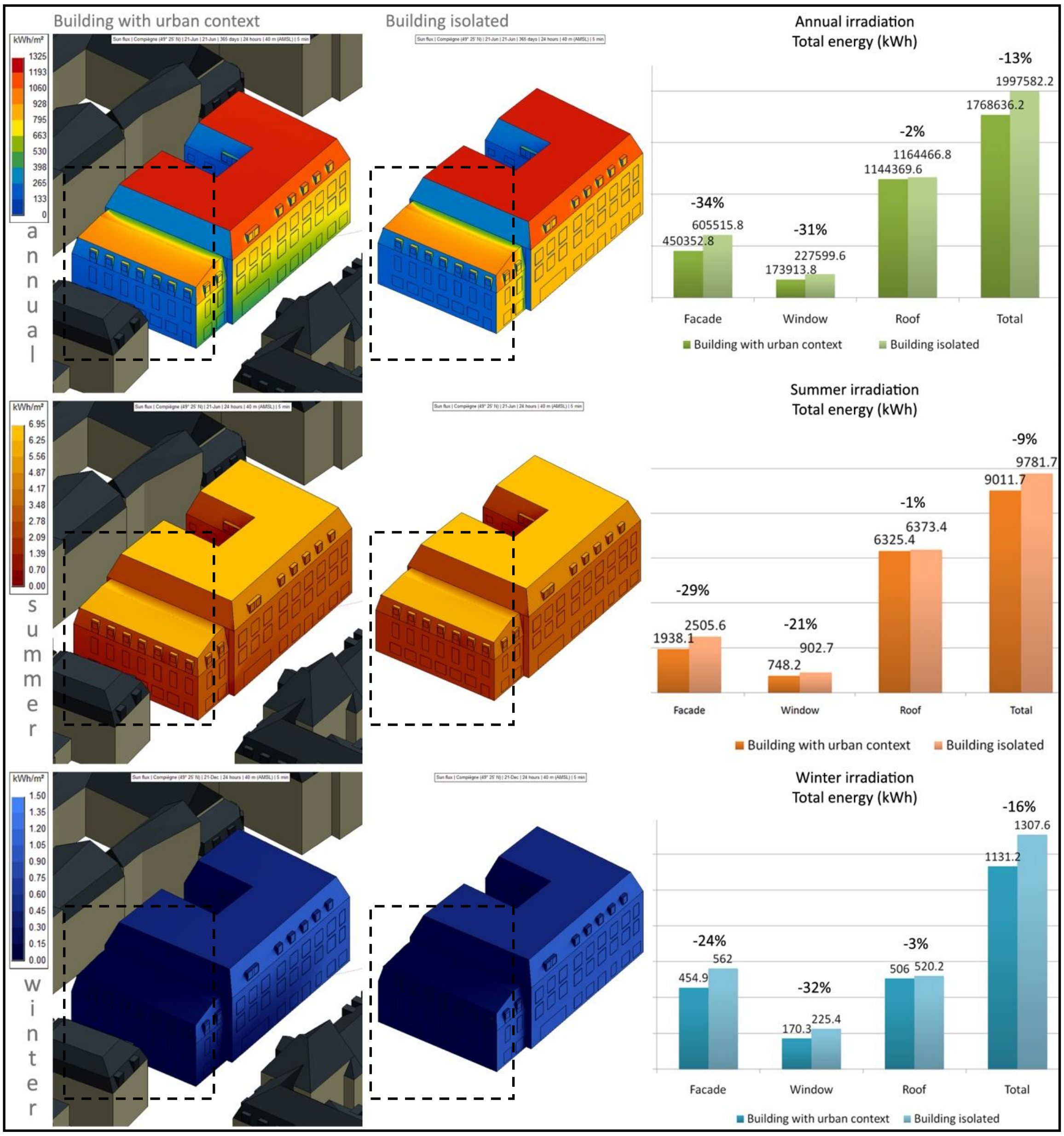

Fig.3 Solar irradiation on a separate building and on the same building with its urban environment.

The histograms show the energy values obtained in the calculations. The percentage corresponds to the diminution of solar gain due to the presence of the urban vicinity. We clearly see that the surrounding built environment reduces seriously the solar gains of a building, especially during the winter, affecting also the possibility of using daylight indoors. So, in order to obtain values closer to reality, to consider the urban context is essential. Correlated applications are the solar rights in the design of urban spaces [3] and impact studies.

4. Results of the sensitivity analysis

The main purpose is to determine the reliability of the simulations and to verify if the level of details obtained from the simplification is appropriate.

4.1 Consideration of windows position through wall thickness

For the purpose of evaluating the influence of the position of the windows with respect to the wall thickness, we select a building of the model (with the windows located at one centimetre out of the wall: first model) and we consider the windows “inside” the wall thickness of 30 centimetres (second model). Simulations of direct solar irradiation have been made for both models, in order to quantify the differences of values and to determinate the feasibility of the addition of the correct position of the windows.

The windows present the most significant looses of energy, produced by the effect of the solar protection of the wall thickness (- 29% in the complete year, - 36% in the summer and -17% in the winter). The windows are very important components of the envelope for the building thermal performance, so it is important to model their real positions on the façade, in order to obtain more accurate energy values. The addition of the wall thickness is easy, however it implies to multiply by three the number of triangles and the calculation time.

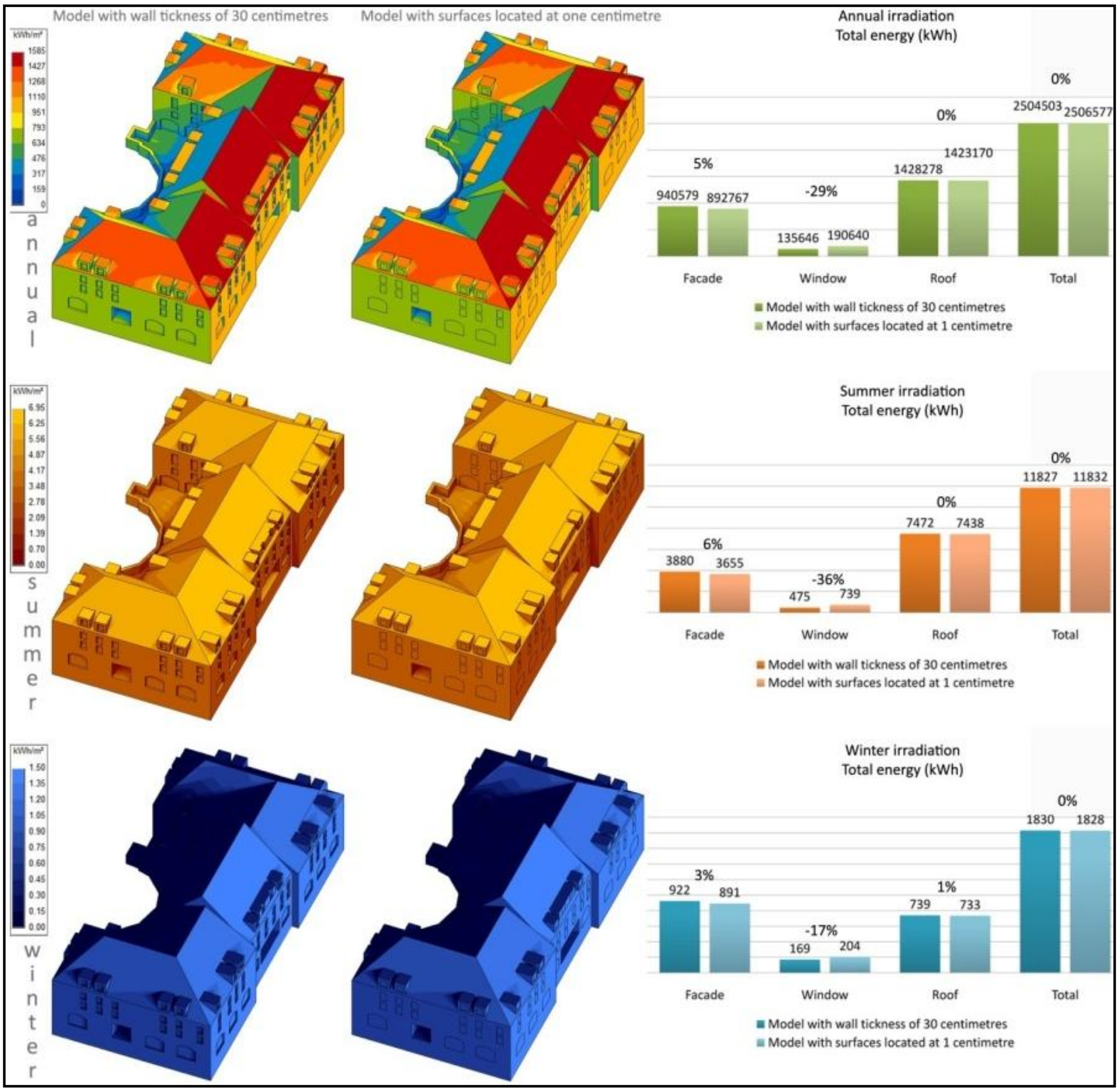

Fig.4 Solar irradiation on a building for two different windows positions.

4.2. Simplification of tilted roofs

In the North of France, the roofs are usually strongly tilted and geometrically complex. However, at the urban scale, most numerical simulations of physical phenomena are performed on models of a level of detail LOD01, which means that the buildings are represented with flat roofs, with a low class of accuracy and an absolute 3D point accuracy (position / height) of 5/5m [4]. In order to measure the margin of error of this procedure and to evaluate if it is necessary to model detailed roofs, a study of solar potential has been realized.

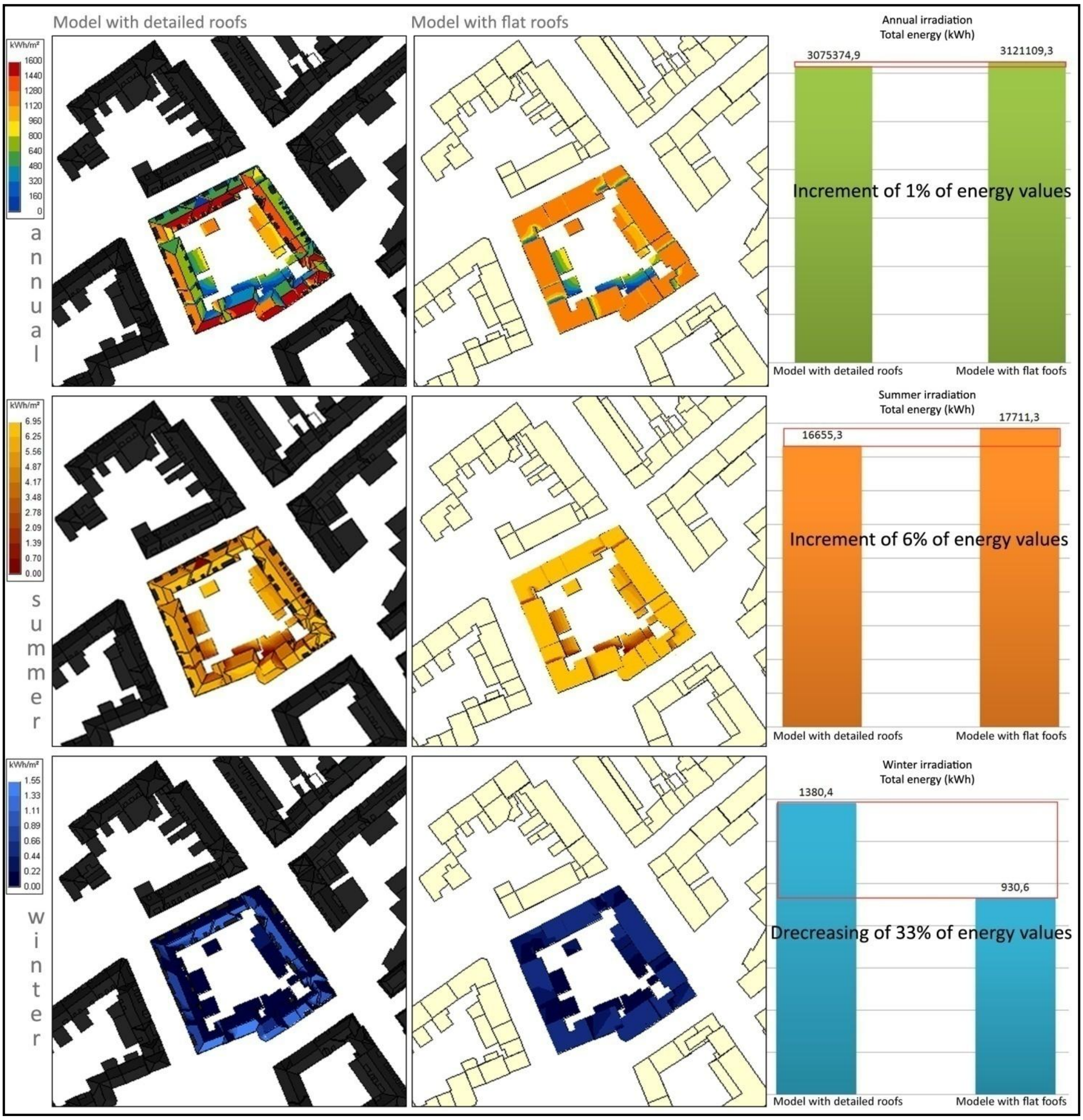

Fig.5 Evaluation of solar potential with detailed roofs and with flat roofs.
(Flat roof area: 2830.12 m^2, detailed roof area: 3554.20 m^2)

The case study shows that differences in the annual calculation are negligible (1%). It seems that the increment of flat roofs in summer (6%) is almost entirely equilibrated by the very significant losses in winter (-33%). Further tests show that the annual change remains generally below 5%.

The results of the annual calculation show that if the objective of the simulation is to evaluate the global site's solar potential, it is possible to use a model LOD01. However, the effect of shadows affects seriously the solar system performance, making the model with detailed roofs necessary to determinate the best location of the panels. We can see that only the model with detailed roofs (top of fig.5) shows in red the best location, as well as the energy values and their distribution. Besides, the computing time is double for the one day (solstice) calculations and 2.5 times more important for the annual calculation, which remains very acceptable.

Model	Calculation time (in seconds)		
	One year	Summer solstice	Winter solstice
Model with flat roofs	360	30	30
Model with detailed roofs	900	60	60

Table 1- Calculations time for one year and for both solstices (in seconds).

5. Roofs typology of northern France region for the evaluation of the site's solar potential.

In northern France, some roofs are difficult to model because of the complexity of their geometry. Based on the results of the sensitivity analysis, it is evident that the elaboration based on a manual approach of a detailed geometry of roofs is very time consuming and computationally demanding. In order to find a compromise between accuracy and computing time, a type of roofs in northern France is being developed. This typology will be composed by elements that can represent any northern Europe city type by introducing the geometry semi-automatically. The main object of the typology is to simplify quantifications of solar gain by varying the urban setting. The typology will be defined and validated through a comparison of the results of the solar potential between two models, the existing model and the other one elaborated with the elements of the typology.

6. Conclusions

The results presented are related to the first step of research we are developing. The level of detail depends on the purpose of the analysis and the accuracy of results. For example, for the impact studies, the assessment of available passive solar gains and daylight, it is necessary to take into account the thickness of the wall, since differences in values are quite large. To calculate the site's solar potential, a model with detailed roofs is necessary in order to determinate the best location for solar active panels. Finally, the evaluation of solar gain of a building within the urban environment becomes essential. For the future, we think that it is necessary to complete the sensitivity analysis with more tests, in order to identify general indicators or correction values that can be applied to the results.

7. Acknowledgements

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